British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The Scottish Government

# CLACKMANNANSHIRE, FIFE and FALKIRK

Mineral Resource Information for Sustainable Communities

## Mineral Resources

Scale 1:100 000

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## SAND & GRAVEL

**Superficial deposits**

| | | |
|---|---|---|
| ■ | Sub-alluvial: Inferred resources | Quaternary |
| ■ | River Terrace deposits | |
| ■ | Glaciofluvial deposits | |
| ■ | Raised Beach deposits | |
| ■ | Blown sand | |

## PEAT

| | | |
|---|---|---|
| ■ | Peat | Quaternary |

## CRUSHED ROCK AGGREGATE

**Igneous rocks**

| | | |
|---|---|---|
| ■ | Quartz-Dolerite sills and dykes (Midland Valley Sill-Complex) | Carboniferous to Early Permian igneous intrusions |
| ■ | Olivine-Dolerite sills and felsic intrusions (Dinantian to Westphalian Sills of Lothian and Fife and Midland Valley Siluro-Devonian Felsic Intrusion Suite) | Silurian to Early Permian igneous intrusions |
| ■ | Other igneous rocks, including basalts, dolerites, trachytes and andesites | Devonian to Early Permian igneous intrusions and volcanic rocks |

## BRICK CLAY

**Superficial deposits**

| | | |
|---|---|---|
| ■ | Lake deposits | Quaternary |

**Bedrock deposits**

| | | |
|---|---|---|
| ■ | Common shale for brick | Carboniferous: Lower Limestone Formation |
| ■ | Common shale for brick coincident with areas of shallow coal | Carboniferous: mainly Lower and Middle Scottish Coal Measures and Limestone Coal Formation |

## BUILDING STONE

■ Important former quarries in Carboniferous sandstones

## LIMESTONE

| | | |
|---|---|---|
| ■ | Limestone | Carboniferous: Lower and Upper Limestone formations |

## SILICA SAND

| | | |
|---|---|---|
| ■ | Resource coincident with fireclay | Carboniferous: Passage Formation |

## SHALLOW COAL

| | | |
|---|---|---|
| ■ | Area of shallow coal coincident with brick clay and fireclay | Carboniferous: mainly Lower and Middle Scottish Coal Measures, Upper Limestone and Limestone Coal formations |
| ▨ | Opencast coal: worked area (up to 2004) | |

## MINERAL WORKINGS

● Active site (with commodity)

| | | | |
|---|---|---|---|
| CBM | Coalbed Methane | Sg | Sand and Gravel |
| Co | Coal | SiS | Silica Sand |
| Ign | Igneous metamorphic rock | Sst | Sandstone |
| Peat | Peat | | |

## ENVIRONMENTAL DESIGNATIONS

▤ National landscape designations (National Parks, National Nature Reserves, Sites of Special Scientific Interest and National Scenic Areas)

▥ International landscape designations (Special Areas of Conservation, Special Protection Areas and Ramsar sites)

\+ Scheduled Monuments

## ADMINISTRATIVE AREAS

— Local Authority boundary

Uncoloured areas on the map indicate undivided bedrock and superficial surface deposits. Unspecified mineral resources may be present locally at surface or at depth.

## Aims and Limitations

The purpose of the maps in this series is to show the broad distribution of those mineral resources which may be of current or potential economic interest and to relate these to selected nationally-recognised planning designations. The maps are intended to assist strategic decision making in respect of mineral extraction and the protection of important mineral resources against sterilisation. They bring together a wide range of information, much of which is scattered and not always available in a convenient form.

The maps have been produced by the collation and interpretation of mineral resource data principally held by the British Geological Survey. Location information on national planning designations has been obtained from the appropriate statutory body (Scottish Natural Heritage, Scottish Government, Joint Nature Conservation Committee and Historic Scotland). For further information the relevant body should be contacted. Note that designated local biodiversity and geodiversity sites are not included in the environmental designation areas shown on the map.

The mineral resource data presented are based on the best available information, but are not comprehensive and their quality is variable. The inferred boundaries shown are, therefore, approximate. Mineral resources defined on the map delineate the surface areas within which potentially workable minerals may occur. These areas are not of uniform potential and also take no account of planning constraints that may limit their working. The economic potential of specific sites can only be proved by a detailed evaluation programme. Such an investigation is an essential precursor to submitting a planning application for mineral working. Extensive areas are shown as having no mineral resource potential, but some isolated mineral workings may occur in these areas. The presence of these operations generally reflect very local or specific situations.

The locations of those quarries active in 2007 are shown. In addition former important building stone quarries are also shown. These have been extracted from the British Geological Survey's Britpits database in February 2008. While the compilers have tried to ensure that the site details are as accurate as possible, any map of active quarries is a snapshot in time. Moving the extraction location as reserves become exhausted or a new extension starts production, and renaming of sites are regular occurrences. Also sites may cease to be active at any time.

The maps are intended for general consideration of mineral issues and not as a source of detailed information on specific sites. The maps should not be used to determine individual planning applications or in taking other decisions on the acquisition or use of a particular piece of land, although they may give useful background information which sets a specific proposal within context.

## BUILDING STONE

Sandstone was the principal building stone quarried for local needs throughout this area, with many quarries operating from the 18th century onwards. A few larger sandstone quarries in the Fife and Falkirk areas also provided building stone to other parts of Central Scotland.

A broad band of sandstones within the Carboniferous succession crops out across Falkirk, the south of Clackmannanshire and south-west Fife. In Fife these Carboniferous sandstones are typically whitish or grey in colour and from the Lower Carboniferous Strathclyde Group or the Upper Carboniferous Passage Formation. In Falkirk sandstone was obtained from the Coal Measures, Upper Limestone and Passage formations.

The quarries in the region were most active during the 19th century. Although production typically ceased in the early decades of the 20th century, some intermittent work continued. The largest quarries, found in Strathclyde Group rocks near Burntisland (e.g. Grange, Newbigging, Cullalo), produced high quality freestone that was used both locally and in cities such as Edinburgh, Dundee and Glasgow. Grange Quarry employed 110 men in 1902, but production had almost stopped by 1914, and Newbigging Quarry closed in 1937 but was temporarily reopened in 1980 and 1984. Cullalo (Cullaloe) Quarry produced a pale sandstone favoured in Edinburgh, but declined after 1898 and was only worked intermittently until 1948. It was reopened in 2004, and remains open, largely to supply building conservation needs in Edinburgh and surrounding areas.

Many of the towns and villages throughout Fife were built using sandstone from the lower and central parts of the Carboniferous sequence. Sandstone from the Strathclyde Group was obtained from small quarries in the Cleish Hills (e.g. in Perth and Kinross at Nivingston, Barns, Cowden Hill, Gaskie Hill), and quarries at Rosyth. Lower Limestone Formation sandstones were quarried at Charlestown, Cowdens (Cowglen) and Craigluscar, and stone for Dunfermline came from the local Duloch and Dunfermline Park (Mill Hill) quarries. Numerous small scale quarries worked sandstones in the Limestone Coal Formation and Upper Limestone Formation in the areas around Carnock, Crossgates, Dunfermline (Berryhaw Quarry), Lochgelly, Kelty, Cardenden and Kirkcaldy. Red and yellow sandstones were worked in several places between Redford and Carberry, north of Kirkcaldy.

Numerous small quarries extracted sandstone from Coal Measures strata in the area around Clackmannan and Alloa, for example the Craigrie and Westfield quarries west of Clackmannan were heavily worked in the late 19th century, typically producing a thick bedded medium to fine grained white sandstone. Darker and more reddish sandstones were produced at quarries around Sauchie. Several quarries around Airth on the south side of the Forth also produced sandstone from the Coal Measures.

The Lower Coal Measures were worked around Alloa and its surrounds where buildings have a distinctive appearance due to the local Devon Red (Middle Coal Mesures) Sandstone. This medium to coarse grained sandstone was quarried throughout the 18th and 19th centuries from a number of quarries in the area (e.g. Devon and Devonbank quarries).

In the Falkirk area, `Cowie Rocḱ sandstone from the Upper Limestone Formation was supplied by a number of quarries. The best known of these was Thorneydyke Quarry, which provided much stone for Stirling. Thorneydyke was active throughout the 19th century and worked intermittently at the start of the 20th century. Today, no active building stone quarries remain in Falkirk and Clackmannanshire. Although many former quarry sites still exist and have not been redeveloped, several of the bigger workings have been landfilled.

Sandstone from the upper part of the Carboniferous sequence (Passage Formation) was worked near Kincardine at Longannet, Blair and Sands quarries. The coastal location of these quarries made their stone suitable for shipment, and they were particularly active during the 19th and early 20th centuries. The workings at Longannet supplied a fine-grained white sandstone as early as the 17th century, and the quarry employed over 150 men in 1910. Stone from Longannet was used locally, as well as being exported by sea to Stirling, Edinburgh, Aberdeen, London and possibly continental Europe. Medium-grained, commonly pale pink sandstones from the Passage Formation were quarried in Clackmannanshire near Tullibody at Knowfaulds, and at the Sheardale and Quarrel Burn quarries near Dollar. The sandstones were used for local buildings, particularly in Dollar. On the south side of the Forth in the Falkirk area several quarries between Cowie and Airth supplied stone, mostly for local needs.

In north and east Fife, relatively few sandstones have been exploited on a large scale, mostly due to distance from markets. In the north, Devonian red sandstones were worked in several areas, for example around Strathmiglo (Drumdreel and Bankwell) and Cupar (Drumdryan Qaurry), whilst along the coast between West Wemyss and Buckhaven small quarries were opened up in Carboniferous sandstones mostly to supply local needs (e.g. Star, Whins Quarry, Treaton, Kennoway, Markinch, Gallatown Quarry, Wemyss Den, and several other sites). Exposures of igneous rocks were less suitable for use as building stone, but some, for example dolerites in the vicinity of North Queensferry, were used locally.

## BRICK CLAY

'Brick clay' is the term used to describe clay and mudstone used predominantly in the manufacture of bricks and, to a lesser extent, roof tiles and clay pipes. These clays may sometimes be used as a source of constructional fill and for lining and sealing landfill sites.

The suitability of a clay for the manufacture of bricks depends principally on its behaviour during shaping, drying and firing. This will dictate the properties of the fired brick, such as strength and frost resistance and, importantly, its architectural appearance.

Most facing bricks, engineering bricks and related clay-based building products are manufactured in large automated factories. These represent a high capital investment and are increasingly dependent on raw materials with predictable and consistent firing characteristics in order to achieve high yields of saleable products. Blending different clays to achieve improved durability and to provide a range of fired colours and textures is an increasingly common feature of the brick industry. Continuity of supply of consistent raw materials is of paramount importance to enable the continuing supply of bricks for construction

Both bedrock and superficial deposits can provide the raw material for brick and tile manufacture; bedrock deposits comprise clay and shale from a variety of sedimentary mudstones, often extracted as a by-product of coal mining. Whereas superficial deposits occur as finely laminated clays and silts formed in lakes and seas during the Quaternary and extraction is made easy as these deposits occur at or very near to the surface and are very soft.

### *Common shale for brick*

In Scotland mudstones quarried or mined from the bedrock have been used in the making of bricks and tiles. Shale or mudstone is usually found interbedded within the other Carboniferous strata. The brick making industry in the region was very heavily linked with coal mining; historically several Carboniferous argillaceous units have been worked as by products of opencast coal mining. The material for brick making was obtained from colliery waste tips (bings) as the high carbon content lowered fuel requirements in the manufacturing process, although the decline of the coal industry has lead to a decline in brick making.

The resources in the Lower Limestone Formation are plentiful. Other mudstones for brick making are found in the Limestone Coal (the Black Metals Marine Band) and the Upper Limestone formations (associated with the Calmy and Orchard limestones) and the Coal Measures. Until recently a quarry at Brotus, Cults worked the 20 to 30 m thick mudstone above the Blackhall Limestone in the Lower Limestone Formation. Future workings could be made in conjunction with opencast working of coal. Other potential resources are thick shale units occurring above the Carboniferous limestone bands; especially the Top Hosie and Index limestones. These could potentially be worked where the drift cover was thin enough but there are no records of any extraction.

The decline in Fife and cessation in Falkirk and Clackmannanshire of coal mining has meant that there is currently no supply of common shale or mudstone in the area. This could change due to increasingly favourable economic conditions for open cast coal, especially the need for higher quality coals.

### *Clay deposits*

There are three main brick clay resources in the Quaternary deposits of the region; the glaciolacustrine laminated silty clays, post glacial clays of a marine origin (Carse Clays and Errol Clay Formation) and estuarine deposits. Both the glaciolacustrine and marine clays have been worked in the past, the glaciolacustrine clays from around Alloa and Dollar for both brick and pottery manufacture. The plastic marine clays were for a long time used in the manufacture of bricks, tiles and field drains for tile manufacture, they have been worked around Grahamston and also just south of the Firth of Forth in Throsk. In Fife marine clays were worked on a small scale at Cupar, Inverkeithing, Cuttlehill, Leven and Linktown, Kirkcaldy, where they were over 6 m thick. At Seafield 7.6 m of stratified brick-clay was formerly seen to rest on till. The grey, clayey silts and silty clays of the Carse Clays are post-glacial and have been worked on a limited scale. The presence of ironstone concretions was deleterious to their quality.

Historically, till has been worked for brick clay often blended with waste materials from old ironstone workings and collieries, however, the heterogeneous nature of till means it does not constitute a modern resource. No clay is produced for brick making in the region, however, till is extracted from Avondale quarry but the end use is for landfill and canal liner due to its impermeable and plastic nature.

## METALLIFEROUS MINERALS

Metalliferous mineral occurence locations are not shown on the map.

The centre of the Midland Valley is mainly underlain by Lower Carboniferous mudstones, limestones and sandstones to the east and by Middle and Upper Carboniferous sandstones, mudstones and minor coals to the west. There is little potential for metalliferous mineralisation in the region. However, there are some records of workings.

### *Silver, Gold and Baryte*

In Clackmannanshire there are several historic workings for silver and other metals in the Alva area. These were discovered in the early 18th Century and produced small amounts of high-grade ore containing several tens of tonnes of silver metal. They are within Lower Devonian volcanic rocks close to the contact with Carboniferous sedimentary rocks and major east-west faults, such as the West Ochil Fault. The British Geological Survey Mineral Reconnaissance Programme investigated the area in 1978 and drilled several boreholes.

The mineralisation is considered to be of the 'five element (Ag-Co-Ni-As-Bi) vein' type whose type locality is at Cobalt, Ontario, Canada. This type of mineralisation generally occurs in swarms of small high-grade veins. Further mineralisation can thus be expected, though not of any great size. The adits, pits and dumps of the known localities can also be expected to continue to attract mineral collectors, both amateur for personal collections and professional dealers for sale. However, it is unlikely that exploration for deposits of commercial size will be undertaken.

The BGS MRP (Minerals Reconnaissance Programme) has also located numerous gold grains in streams draining the Ochil Hills. The main area was in Glen Devon and very few grains were found in Clackmannanshire. The source of the gold has not yet been proved, but it is thought to be associated with the extensive Lower Devonian lavas in the area, especially where they have been hydrothermally altered by mineralising solutions. The lavas extend south-west into Clackmannanshire. It is unlikely that any intensive exploration will take place because any deposits is likely to be small and the environmental sensitivity of the area may affect any substantial development

Fife does not appear prospective for the occurrence of metalliferous or related mineralisation. Nevertheless it is possible that minor baryte veins may exist. It is unlikely that any exploration will be carried out in the area. Galena occurs in veins associated with thick beds of limestone.

The only significant recorded mineralisation in Fife is the occurrence of several small isolated baryte veins, often with associated copper minerals. A few veins of lead ore are said to have been worked between East Lomond Hill and Glenrothes but they are not regarded as significant. The largest of these is supposedly silver-bearing galena (PbS) vein, trending north-east behind the farmhouse at Hanging Myre, south of East Lomond Hill. It was trialled after being discovered in 1783; also at Castlelandhill, Rosyth.

### *Ironstone*

In the past both nodular and bedded clayband ironstone and blackband ironstone have been mined in the Kirkcaldy district. The most extensive were the claybands in the mudstone roof of the Lower Dysart Coal. The Lochgelly Blackband Ironstone was worked at Lochgelly and Kilmux. These are unlikely to be economic resources.

The only ironstone band known to have been mined in east Fife was the Denhead Blackband Ironstone from the Lower Limestone Formation. It was mined out in 1866. The Kelty Blackband (LImestone Coal Formation) was worked at Kelty.

### *Ochre*

Historically yellow ochre (hydrated iron oxide) has been quarried at Letham Glen, Leven and mined at the Leven and Durie collieries, from the Middle Coal Measures (from above the Pilkembare Coal to the top of the formation) and from the Upper Coal Measures.

## SILICA SAND

Silica (industrial) sands contain a high proportion of silica ($SiO_2$) in the form of quartz and are used for purposes other than construction. They are essential raw materials for the glass and foundry castings industries, but can also be used in ceramics and chemical manufacture, water filtration media and in sports and horticultural applications. They are produced from both loosely consolidated sand deposits and by crushing weakly cemented sandstones. The important chemical characteristics are the high quartz content and the low levels of impurities, particularly clay, iron oxides and refractory minerals such as chromite. Silica sands typically have a narrow grain size distribution, generally in the range 0.5 mm to 0.1 mm, although coarser grades are required for some applications. Generally silica sands have to conform to very closely defined specifications and consistency in quality is of critical importance. Particular uses often require different combinations of properties. Consequently, different qualities of silica sand are usually not interchangeable in use. Silica sands command a higher price than constructional sands and this allows them to serve wider geographical markets, including overseas. Within the UK deposits of silica sand occur in only limited areas and quantities, and the special characteristics of silica sand extraction, in particular the cost of processing, means that the industry has a restricted distribution.

Both regionally and nationally important sources of silica sand occur in the Carboniferous Passage Formation in Fife, Falkirk and Clackmannanshire; this comprises lensoidal bodies of easily disaggregated soft quartz rich sandstones with an optimum composition of moulding sands. The sand has industrial uses including glass-making as well as use as building sand for less pure components. Sands for industrial use are currently extracted at Burrowine Moor and Devilla Forest near Kincardine-on-Forth. The Burrowine Quarry produces the purest glass sand within central Scotland. Although other locations in Scotland have been examined, with the demand for increased purity, the number of suitable sites is restricted. The silica sands come from sandstones near the No. 3 Marine Bands in the Passage Formation. In the Devilla Forest Quarry a 10 m thick white sandstone is partly iron-stained but is composed of 98% $SiO_2$. The best quality sand used for colourless flint glass containers is produced by acid washing of the clay-free sand. The non-acid treated sand is used for washed moulding sand and coloured glass production. In Burrowine Quarry the sandstone 10-15 m thick, is white with some iron-staining. By selective working, a glass sand with about 99% $SiO_2$ and 0.02% iron oxide is produced for colourless glass.

In Falkirk and Clackmannanshire the Passage Formation occurs surrounding the Coal Measures in the Central Coalfield syncline. Unfortunately superficial deposits conceal much of the formation here and consequently there have been no significant modern workings.

The blown sands occuring near Pettycur, St Andrews Bay and Tentsmuir Forest are also potential coloured glass sands as they have a high silica content. The sands at Pettycur have previously been used for bottle glass.

## CRUSHED ROCK AGGREGATE

A variety of hard rocks are, when crushed, suitable for use as aggregates. Their technical suitability for different applications depends on their physical characteristics, such as crushing strength and resistance to impact and abrasion. Higher quality aggregates are required for coating with bitumen for road surfacing, or for mixing with cement to produce concrete. For applications such as constructional fill and drainage media, with less demanding specifications, lower quality materials are acceptable.

The crushed rock resources in the region are entirely comprised of igneous rocks, these tend to produce strong aggregates with a degree of skid resistance and are hence suitable for many road-surfacing applications as well as for use in the lower parts of the road pavement. The igneous aggregate produced in Fife, Falkirk and Clackmannanshire has a variety of uses from roadstone, including high specification varieties, coated roadstone, railway ballast, concrete aggregate, decorative stone, constructional fill, horticultural sand and armourstone.

The main sources of aggregate are the late-Carboniferous quartz-dolerite intrusions and the Lower Devonian and Carboniferous lavas and intrusions. In general the hard rock characteristics of lavas are not as consistent as those for intrusive rocks because they tend to be more variable in thickness, lateral extent and quality. In the past vertical intrusions (dykes) of quartz-dolerite and related basaltic rock have been quarried but these are only a few metres wide (max 30-40 m) and are no longer considered to be economicable to quarry.

The highest quality and most worked resource in the region is a series of quartz-dolerite sills belonging to the Carboniferous Midland Valley Sill Complex. These are of various thicknesses (30-150 m) but are relatively homogeneous and fresh. The active quarries produce a number of high specification products such as crushed rock for road stone, coated road stone and ready mix concrete; demand for these products is unlikely to decline making quartz-dolerite one of the regions most important resources.

Many small outcrops have been worked out but resources are still considerable around Denny where there are active operations at Boards, Cowdenhill and Northfield as well as to the south-west of Linlithgow. Quartz-dolerite sills are not so abundant in the Clackmannanshire district but do occur to the north of Dollar and were worked at Gloom Hill Quarry. In Fife a quartz-dolerite sill quarry is situated at Devon near Kennoway. A similar sill is quarried at Cruicks, Inverkeithing. There is potential for quarrying in the Kilmux area.

Other high specification crushed rock resources come from olivine-dolerite and basalt intrusions although they tend to be of a lower quality then the quartz dolerites. At Langside Quarry, Kennoway, a Carboniferous olivine-basalt vent intrusion waa quarried. Another Carboniferous sill at Lochhead is quarried for roadstone but is also part of a landfill site. Disused quarries include workings of an olivine-dolerite at Craigs near Auchterderran and at Belliston. At Kilbrackmont in east Fife a Lower Devonian lava (olivine-basalt) was quarried in the past for roadstone. A quarry in a pink rhyolitic intrusion of Devonian age at Lucklawhill near Balmullo has a specialist market including high specification roadstone and decorative purposes.

The other crushed rock resource in the region comes from basaltic lavas and associated intrusions. In general the hard rock characteristics of lavas are not as consistent as those for intrusive rocks because they tend to be more variable in thickness, lateral extent and quality. The lavas occur in four main areas; to the north-west of Denny where the Clyde Plateau Volcanic Formation covers large areas, to the west of Linlithgow where the Bathgate Hills Volcanic Formation crops out, the Kinghorn Volcanic Formation to the west of Kinghorn and the Ochil Hills formed by Lower Devonian basalts and conglomerates. There are no workings in the Clyde Plateau or Bathgate Hills Volcanic formations due to the abundance of nearby higher quality quartz-dolerite. The lavas here are commonly rotten and heterogeneous but could potentially provide crushed rock for sub-road base and imported fill. The Carboniferous lavas of the Kinghorn Volcanic Formation have been quarried. The main site of extraction is at Orrock, here Carboniferous basaltic lavas are obtained from the quarry near Stenhouse Reservoir and they have been used in the production of rockwool in the past. The Ochil Volcanic Formation is the most abundant resource and covers a large area of Clackmannanshire and Fife. It comprises up to 2400 m of lava flows which individually vary considerably from thin weak rotten rocks to 30 m thick relatively fresh flows. The economic potential for most of this deposit is severely limited by its remoteness. There are two active quarries, one at Craigfoot to the north of Tillicoultry which works andesite and volcaniclastic rocks hardened by thermal alteration by nearby diorite intrusions. The quarry originally worked a quartz-dolerite fault intrusion. The rock here has a relatively low shrinkage and so is suitable for most concreting specifications and is also hard enough for use as rail ballast. The only other quarry within the Ochil Volcanic Formation is the Clatchard Craig Quarry at Newburgh, working a thick, fresh andesitic lava.

## LIMESTONE

Limestones are sedimentary rocks composed mainly of calcium carbonate ($CaCO_3$). With an increase in magnesium carbonate ($MgCO_3$) content they grade into dolostone ($CaMg(CO_3)_2$). Most limestones and dolostones are hard and durable and useful for aggregate. They are common rock types and consequently widely extracted for aggregate materials although generally this is not considered in central Scotland as there are numerous hard rock alternatives. Limestone is also used for cement manufacture and both limestone and dolomite are valued for a range of industrial uses which, like cement manufacture, utilise their chemical properties.

Limestone uses are broadly categorised into three groups; chemical uses, cement manufacture and constructional use. The latter has hardly been considered in central Scotland as there are numerous hard rock alternatives. The former two uses have more strategic considerations, such as chemical composition and adequate supply.

Limestone resources in the region are concentrated in Fife. Here quarrying was formerly extensive, working the numerous relatively thin (about 3 m thick) limestones in the Carboniferous Lower and Upper limestone formations. The limestones in the Lower Limestone Formation (Hurlet and Blackhall equivalents) were the most exploited units. The Burdiehouse Limestone of the Sandy Craig Formation was quarried and mined around Burntisland. The St Monans White Limestone of the Pathhead Formation was also quarried in the past.

Resources that were readily available near the surface are mostly exhausted and mining is likely to be too expensive a prospect, although at one time limestone was commonly mined, for example at the Newbigging Mine west of Burntisland. Limestone from the Charlestown Station Limestone (Hurlet Limestone) was also formerly worked in mines at Cults (Skelpie) and Teasses for asphalt filler, calc-silicate bricks and agricultural lime. These mines also produced lime with a low silica content suitable for mine dusting, but certain dolomitic layers prevented use in cement manufacture. The last working operation was a small opencast pit adjacent to the abandoned mines at Cults. Analyses of the St Monance Brecciated Limestone show that it is dolomitised to varying degrees (ranging from 1.5-15.4% and less than 2% acid insoluble material) restricting its use. Bedded dolomites formerly quarried near Crail are no longer exposed and no analyses are known.

In east Fife, most quarries were in the St Monance Brecciated Limestone (Hurlet Limestone) which is up to 3.5 m thick.

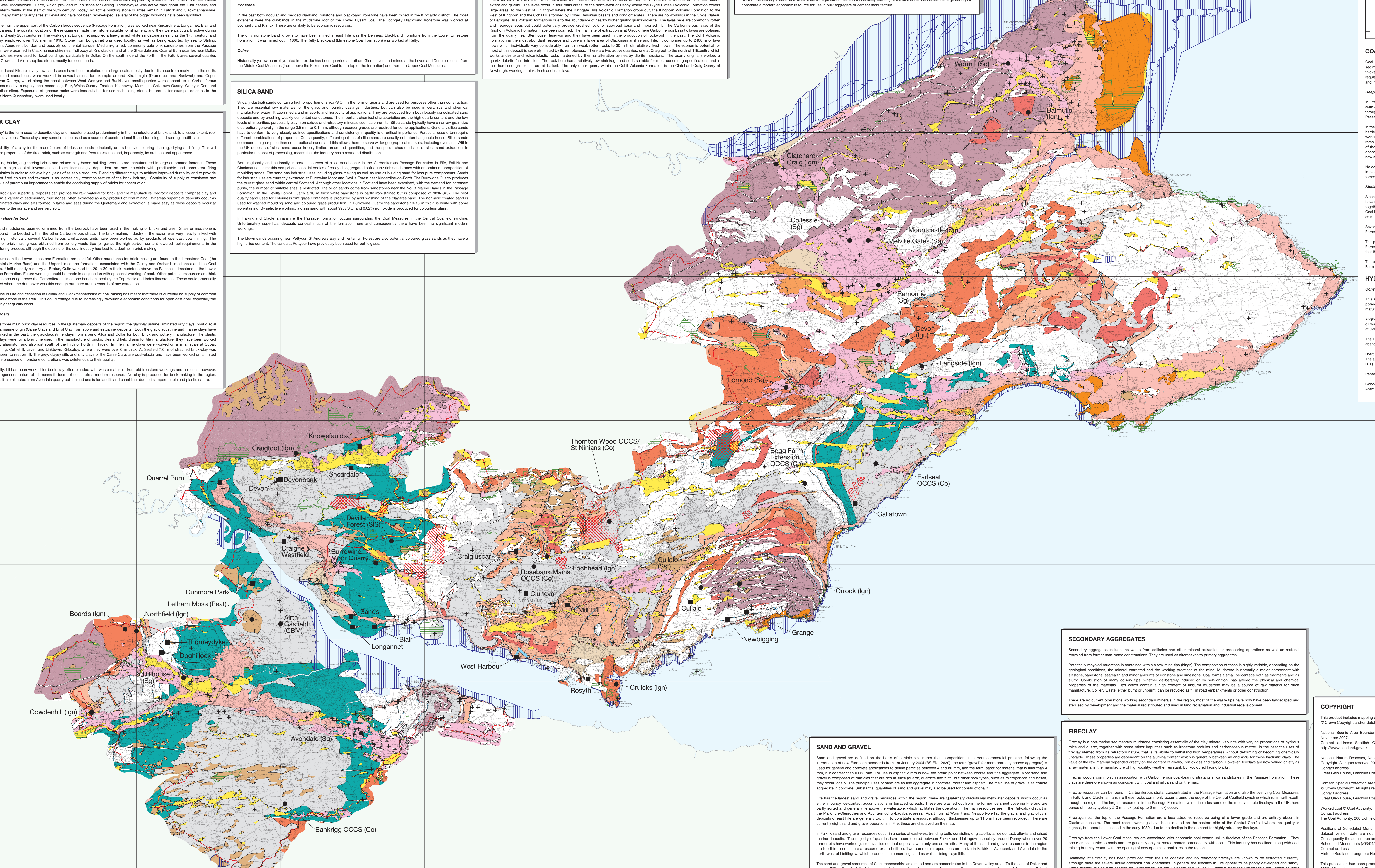
In the Upper Limestone Formation, the Castlecary Limestone was quarried at Hatton where it is over 4.5 m thick, among other small scale workings and also the Calmy Limestone was worked to some extent. The limestones in the Upper Limestone Formation are currently considered to be too thin to be economically worked although it is possible that the Upper Limestone Formation to the east of Stirling could hold resources although this remains to be tested.

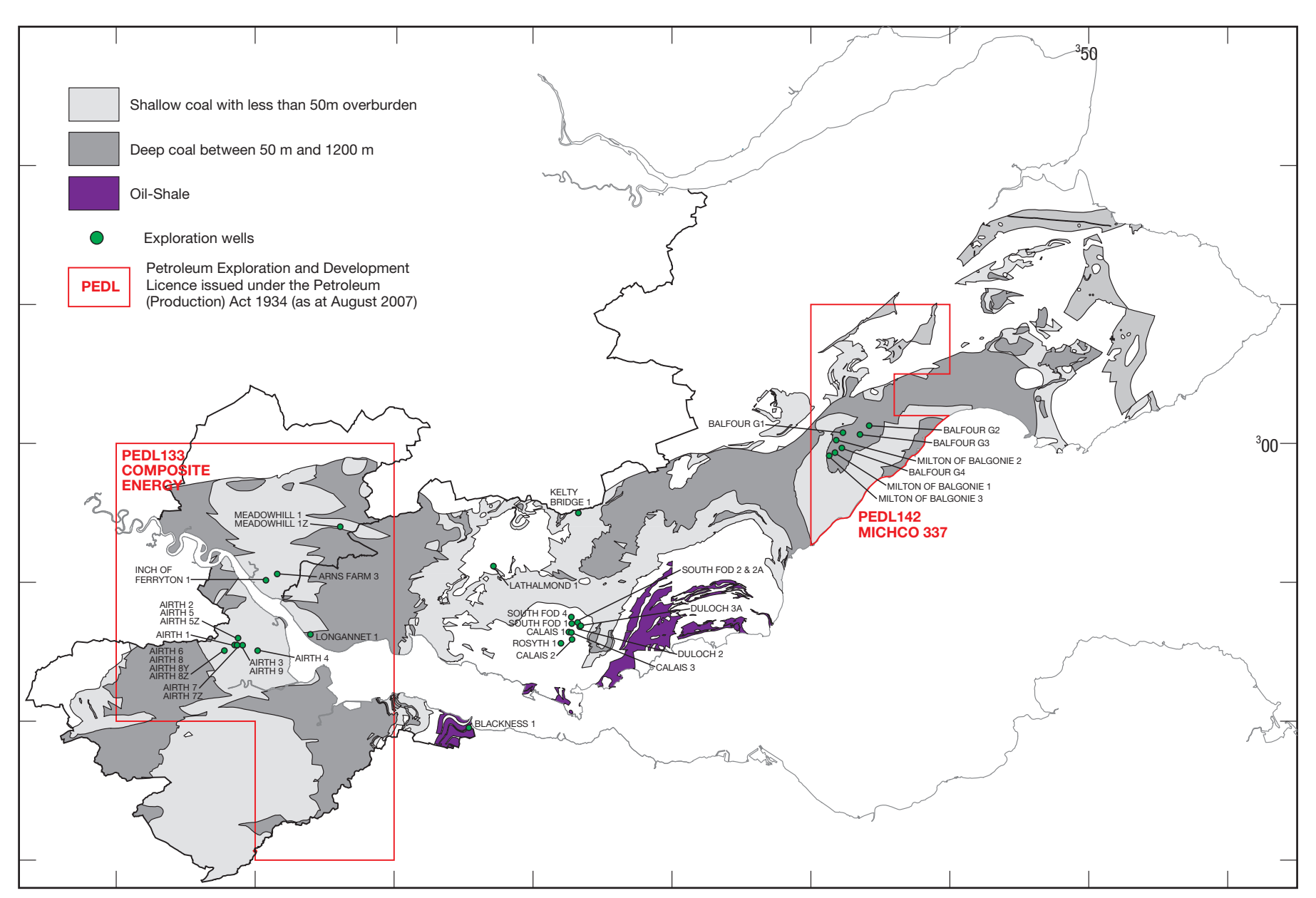
In Falkirk and Clackmannanshire limestone resources are limited; there are almost no records of workings in Clackmannanshire apart from for minor agricultural use. In Falkirk there are records of limestone workings in the Upper and Lower limestone formations, notably the Hurlet, Calmy and Castlecary limestones. The Castlecary Limestone is of high quality lime and has been the most extensively mined. Most of the workings were on a small scale for agricultural use and it is unlikely that any of the limestone units would be large enough to constitute a modern economic resource for use in bulk aggregate or cement manufacture.

## PEAT

This is an unconsolidated deposit of plant remains in a water-saturated environment such as a bog or fen. Bogs occur in areas that are dependent on rainfall for supply of water and the vegetation is characterised by acid tolerant plant communities of which the genus *Sphagnum* is dominant. The two main types of bog are (i) raised bogs, characteristic of flat underlying topography and found on plains and broad valley floors and (ii) blanket bogs, which occur mainly in upland areas where conditions are suitably cool and wet. Although once dug for fuel peat is now mainly a resource for the horticultural industry.

The peat resources in the region are moderate, with two commercial operations in Falkirk at Letham Moss and Gardrum Moss, both being worked for horticultural purposes. It was also formerly produced from Darnrig Moss. The greatest areas of peat cover are in the south of Falkirk around Slammannan, although considerable areas have been cleared as a result of land beneficiation and there are no active workings. Extensive areas of peat are relatively rare in Fife but include Star Moss, near Markinch, Auchterderran and Woodend In Clackmannanshire thick peat cover can be found throughout the Ochil Hills, however the deposits are remote and access is very poor.





## COAL

Coal is a combustible sedimentary rock made of lithified plant remains. It is formed by the progressive biological and thermal degradation of vegetation, which is consolidated between other sedimentary rocks, notably seatearth, mudstone, siltstone and sandstone, to form coal seams (layers). These vary in thickness from a few centimetres up to rarely 3.5 m, although exceptionally thicker seams may also occur. Almost all onshore coal resources in Scotland occur in rocks of Carboniferous age (300 - 330 million years old) and the main strata containing coal seams at fairly regular intervals are referred to as coal measures. The bedrock formations in Fife, Falkirk and Clackmannanshire are mainly Carboniferous in age and as such include coals, limestones, mudstones and ironstones that formed the basis of the industrial development of the region in the 19th and 20th centuries. Most extraction ceased as deep mining and heavy industry became uneconomic.

### *Deep-mined coal*

In Fife coal seams are present in most of the Carboniferous formations but particularly the Limestone Coal Formation (with about 20 named seams) and the Lower and Middle Scottish Coal Measures (with over 20 named seams). Falkirk and Clackmannanshire are well endowed with coal resources, and the Central Coalfield Syncline, which contains most of the resource, runs from north to south through the region. The coal seams are confined to the Limestone Coal and Upper Ilmestone formations (especially the Upper Hirst Coal) and the Middle and Lower Coal Measures. In the past the Passage Formation and Upper Limestone Formation were worked.

In the future seams at depth under the Forth estuary and the Firth of Forth could be mined or drilled for coal-bed methane. Modern mining would require a seam thickness of over 1.4 m and suitable barriers against the entry of mine waters from abandoned workings. There is undersea potential in the Coal Measures in the former Michael, Frances and Seafield collieries. A feature of these offshore workings was the locally adopted special method of longwall-mining to cope with the steep dips. In the Limestone Coal Formation, there is potential both undersea and onshore. Some resources remain under the Leven Syncline to the east of the Rothes Colliery, which had to close on account of the thinning coals, igneous intrusions and excess minewaters. Further resources occur to the east of the undersea workings in the Seafield Colliery, which worked little coal from this formation because of the thinness of the seams and the steep dips. Deep mining has ended at Longannet but opencast coal production is continuing with the development of larger scale and more efficient plant. A large area of Upper Hirst Coal in the Kincardine Bridge area south of Forth could be mined from new sinkings.

No coal has been mined in east Fife since 1945 partly because the coal seams are faulted and folded and have igneous intrusions. Most of the easily mined coal has been worked but as the workings in places such as at St Monans stretch back to the 17th century, their details are incomplete. In Falkirk and Clackmannanshire coal was once a thriving industry but now economic conditions have forced the closure of all the deep pits, the last being Polkemmet Colliery in 1985.

### *Shallow coal*

Since the privatisation of the coal industry, there has been active interest in the open casting of coal. One of the main targets has been the Coal Measures where the 3-12 m thick Dysart Main and Lower Dysart coals are accessible. The Limestone Coal Formation also has potential. In the Westfield Basin there were also thick coals in the Passage Formation, which are essentially worked out together with those in the overlying Coal Measures. In the past there has been interest in the heat-affected seams that had been coked or anthracitised by dolerite intrusions, such as in the Limestone Coal Formation around the Cadham area. The Upper Limestone Formation may be a resource in the Bowhill area, and also Kilmux and particularly the Pilmuir areas where the Carhurlie Coal may be as much as 2 m thick. North of Kirkcaldy, the Lethemwell Coal in the Passage Formation may also be a possible resource.

Several coal opencast pits are still operating in Fife. In the Lower Coal Measures operations are at; Earlseat in the Dysart Main Coal and the Kingslaw site near Kirkcaldy. In the Limestone Coal Formation operations are at Rosebank Mains near Dunfermline, Begg Farm near Cluny and Greenbank/St Ninians near Lassodie.

The possibility of opencast operations exists in east Fife where not only are coal seams present in the Limestone Coal Formation but several seams are well developed in the Lower Limestone Formation and Sandy Craig Formation (Back and Fore coals). In fact the most extensively worked seam in east Fife is the Largoward Splint Coal which was locally over 1 m thick. Boreholes proved that the seams are similarly developed to those in the west of Fife.

There are no operations in Falkirk and Clackmannanshire where the last two opencast coal sites have closed in recent years. The Back Coal (3 m thick) was a mine target for the NCB. The Meadowhill Farm site completed coaling in January 2005. The Bankrigg site closed in May 2006.

## HYDROCARBONS

### *Conventional Oil and Gas*

This area lies within the late Palaeozoic Midland Valley graben, which has a proven hydrocarbon system. A thick sequence of Carboniferous rocks includes oil-shale source rocks, thin sandstones as potential reservoirs and interbedded mudstone seals. Many of the compressive and transpressive structures were formed during the Variscan deformation at the end of the Carboniferous. The organic maturity of the source rocks has been shown to lie within the oil window in most places, although overmaturity occurs in the vicinity of the Midland Valley Sill Complex.

Anglo-American drilled initially on the Rosyth Anticline in 1940. Caprock drilled farther north at Duloch 1 in 1966, following up the British Geological Survey's Duloch West discovery of 1965, in which oil was produced from a sandstone at the top of the Strathclyde Group. Anvil then drilled Duloch 3 and 3A in 1981, which found oil shows. Anvil initially, then Berkeley drilled three very shallow wells at Calais, targeted at sandstones above the Midland Valley Sill. Calais 3 had gas shows.

The Blackness dome was tested by the Anglo-Iranian company D'Arcy in 1945 but contained poor shows. A well located by seismic, at Inch of Ferryton, was drilled by Tricentrol in 1986 and abandoned as dry.

D'Arcy drilled four wells at Balfour in 1938, on the surface anticline to locate a suitable structural position for a deeper test. These wells had oil shows but a deeper well was never drilled by D'Arcy. The anticline lies west of the Leven Syncline, forming the Fife Coalfield. Using seismic Burmah drilled Milton of Balgonie 1 in 1984 on this anticline, which discovered oil and is listed as a discovery by DTI (Table 1). The oil produced was heavy, with high wax. This was followed by two further appraisals by Pentex (in 1986 and 1988), without establishing production.

Pentex also drilled at Lathalmond, which was abandoned with minor oil shows in 1990.

Conoco acquired seismic data under a DTI 'onshore licence' in the Firth of Forth (estuaries are part of onshore licensing) and drilled Firth of Forth 1 (25/26-1, Table 1) along strike from the Cousland Anticline, on the seabed Namurian crop. A fluid sample from the Sandy Craig Formation contained traces of oil and gas and there were numerous other shows, but the well was abandoned in 1990.

| Number | Name | Operator | Licence | Released | Status |
|---|---|---|---|---|---|
| LF/25-1 | Balfour G1 | D'Arcy | A89 | N | Plugged & abandoned |
| LF/25-2 | Balfour G2 | D'Arcy | A89 | N | Plugged & abandoned |
| LF/25-3 | Balfour G3 | D'Arcy | A89 | N | Plugged & abandoned |
| LF/25-4 | Balfour G4 | D'Arcy | A89 | N | Plugged & abandoned |
| LF/25-5 | Milton of Balgonie 1 | Burmah | PL253 | Y | Discovery |
| LF/25-6 | Milton of Balgonie 2 | Pentex | PL253 | Y | Plugged & abandoned |
| LF/25-7 | Milton of Balgonie 3 | Pentex | PL253 | Y | Plugged & abandoned |
| LF/27-9 | Longannet 1 | Composite | PEDL133 | N | CBM |
| LF/28-1 | Rosyth 1 | Anglo-American | A93 | Y | Plugged & abandoned |
| LF/28-2 | Calais 1 | Caprock | A459 | Y | Plugged & abandoned |
| LF/28-3 | South Fod 1 | Caprock | A459 | Y | Plugged & abandoned |
| LF/28-4 | Calais 2 | Anvil | XL133 | Y | Plugged & abandoned |
| LF/25-5 | South Fod 4 | Anvil | XL133 | Y | Plugged & abandoned |
| LF/28-6 | Calais 3 | Berkeley | PL223 | Y | Plugged & abandoned |
| LF/28-7 | Lathalmond 1 | Pentex | EXL096 | N | Plugged & abandoned |
| LF/29-1 | Duloch 2 | Caprock | A459 | N | Plugged & abandoned |
| LF/29-2 | South Fod 2 & 2A | Anvil | XL133 | Y | Plugged & abandoned |
| LF/29-3 | Duloch 3A | Berkeley | XL133 | Y | Plugged & abandoned |
| L25/26-1 | Firth of Forth 1 | Conoco | EXL026 | Y | Plugged & abandoned |
| LF/26-1 | Airth 6 | Composite | PEDL133 | N | Development |
| LF/26-2 | Airth 8 | Composite | PEDL133 | N | Development |
| LF/26-2Z | Airth 8Z | Composite | PEDL133 | N | Development |
| LF/26-2Y | Airth 8Y | Composite | PEDL133 | N | Development |
| LF/26-3 | Bandeath 1 | Composite | PEDL133 | N | CBM |
| LF/27-1 | Inch of Ferryton 1 | Tricentrol | EXL001 | Y | Plugged & abandoned |
| LF/27-2 | Airth 1 | Hill Farm Coal | EXL237 | Y | CBM |
| LF/27-3 | Airth 2 | CBM Ltd | EXL237 | N | Appraisal |
| LF/27-4 | Airth 3 | CBM Ltd | EXL237 | N | Appraisal |
| LF/27-5 | Airth 4 | CBM Ltd | EXL237 | Y | Appraisal |
| LF/27-6 | Arns Farm 3 | CBM Ltd | EXL237 | Y | CBM |
| LF/27-7 | Airth 5 | Composite | PEDL133 | N | Development |
| LF/27-7Z | Airth 5Z | Composite | PEDL133 | N | Development |
| LF/27-8 | Airth 7 | Composite | PEDL133 | N | Development |
| LF/27-8Z | Airth 7Z | Composite | PEDL133 | N | Development |
| LF/27-10 | Meadowhill 1 | Composite | PEDL133 | N | CBM |
| LF/29-5 | Kelty Bridge 1 | Anvil | PL223 | Y | Plugged & abandoned |
| LH/03-2 | Blackness 1 | D'Arcy | A104 | N | Plugged & abandoned |

Table 1. Exploration wells and others not related to producing fields. All the Airth wells have been included because some have been abandoned and it is not known which wells might form productive wells within the field (Table 2).

| Field | Date | Company Discovery | Oil/gas/CBM | Operator | Exhaust date | Production bcm |
|---|---|---|---|---|---|---|
| Airth | 1993 | Hill Farm Coal | CBM | Composite Energy | | 0.0155 |

Table 2. CBM gasfields in development

### *Abandoned Mine Methane (AMM), Coal Mine Methane (CMM) and Coalbed Methane (CBM) potential*

Hill Farm Coal drilled an initially promising coalbed methane prospect at Airth, which was put on long-term test in order to dewater the coal seams. Coalbed Methane Ltd took over the licence and drilled four more wells including Arns Farm 3 by 1998, but relinquished the licence in 2003. Composite Energy secured the licence in 2004 and has applied horizontal well completion techniques to improve gas production. Four more well sites, with deviated sidetracks, have been drilled, with two more planned. DTI gave approval for the development of the field in January 2007. This is likely to be the UK's first coalbed methane producing field.

The main reservoir coals are the Bannockburn Steam and Bannockburn Main, which lie near the middle of the Limestone Coal Formation. The company estimated the gas resources were 3 tcf, in 2006.

The Composite Energy coalbed methane licence PEDL 133 extends from Falkirk into western Fife. The first well on the Longannet prospect was drilled, in 2007, where the company envisages a 6-well development. Published information by the National Coal Board showed that the Upper Hirst Coal in the Longannet Colliery complex coal faces, in 1982, had an average seam gas content of 2.7 $m^3$/tonne at Bogside and 0.4 $m^3$/tonne at Castlehill. Older coal seams would be expected to reach the higher values known at Airth.

Michco 337 and Octagon Energy currently hold the PEDL 124 licence over the Milton of Balgonie discovery (Table 1). There is no published record of their exploration plans but coalbed methane and abandoned mine methane would appear to be more likely than conventional hydrocarbon exploration. In the Frances Colliery, published National Coal Board data showed that the Bowhouse seam had an average seam gas content of only 0.6 $m^3$/tonne and the Dysart Main seam at Seafield 1.2 $m^3$/tonne. Both seams are in the Lower Coal Measures: older seams should have higher contents.

## OIL-SHALE

Oil-shale is the term used to described a fine-grained sedimentary rock with a high enough organic content to make it possible to extract hydrocarbons. This extraction is energy intensive so to be economic deposits have to be sizable. The only recorded oil-shale extraction in the region was in Fife. Here oil-shale was once mined at the Burntisland Oil-shale Works where the Fife Dunnet Shale belonging to the Sandy Craig Formation was the only bed thick enough to be worked at up to 2 m thick. The Westfield Shale in the Passage Formation was also exploited in the Westfield Basin where it was up to 2 m thick. Locally, inland of Anstruther shafts were sunk to test shale in the Anstruther Formation.

Falkirk and Clackmannanshire have no history of oil-shale extraction; however the Hopetoun Member, part of the West Lothian Oil-Shale Formation, which can be found north of Linlithgow, was a productive oil-shale source rock in West Lothian so may contain resources. Just south of the region, north of Bathgate a seam at the base of the Lower Coal Measures was worked for 12 years from 1851, it is possible similar deposits could occur in equivalent rocks in Falkirk, however no such units have as yet been found. Oil-shale is only shown on the inset map.

## SAND AND GRAVEL

Sand and gravel are defined on the basis of particle size rather than composition. In current commercial practice, following the introduction of new European standards from 1st January 2004 (BS EN 12620), the term 'gravel' (or more correctly coarse aggregate) is used for general and concrete applications to define particles between 4 and 80 mm, and the term 'sand' for material that is finer than 4 mm, but coarser than 0.063 mm. For use in asphalt 2 mm is now the break point between coarse and fine aggregate. Most sand and gravel is composed of particles that are rich in silica (quartz, quartzite and flint), but other rock types, such as microgabbro and basalt, may occur locally. The principal uses of sand are as fine aggregate in concrete, mortar and asphalt. The main use of gravel is as coarse aggregate in concrete. Substantial quantities of sand and gravel may also be used for constructional fill.

Fife has the largest sand and gravel resources within the region; these are Quaternary glaciofluvial meltwater deposits which occur as either moundy ice-contact accumulations or terraced spreads. These are washed out from the former ice sheet covering Fife and are partly sorted and generally lie above the watertable, which facilitates the operation. The main resources are in the Kirkcaldy district in the Markinch-Glenrothes and Auchtermuchty-Ladybank areas. Apart from at Wormit and Newport-on-Tay the glacial and glaciofluvial deposits of east Fife are generally too thin to constitute a resource, although thicknesses up to 11.5 m have been recorded. There are currently eight sand and gravel operations in Fife; these are displayed on the map.

In Falkirk sand and gravel resources occur in a series of east-west trending belts consisting of glaciofluvial ice contact, alluvial and raised marine deposits. The majority of quarries have been located between Falkirk and Linlithgow especially around Denny where over 20 former pits have worked glaciofluvial ice contact deposits, with only one active site. Many of the sand and gravel resources in the region are too thin to constitute a resource or are built on. Two commercial operations are active in Falkirk at Avonbank and Avondale to the north-west of Linlithgow, which produce fine concreting sand as well as lining clays (till).

The sand and gravel resources of Clackmannanshire are limited and are concentrated in the Devon valley area. To the east of Dollar and around Tillicoultry glaciofluvial ice contact deposits have been worked, however, these contain deleterious coal fragments. Raised marine gravel and sub-alluvial deposits remain possibilities for sand and gravel resources but many of the deposits lie below the water table making extraction costly.

## SECONDARY AGGREGATES

Secondary aggregates include the waste from collieries and other mineral extraction or processing operations as well as material recycled from former man-made constructions. They are used as alternatives to primary aggregates.

Potentially recycled mudstone is contained within a few mine tips (bings). The composition of these is highly variable, depending on the geological conditions, the mineral extracted and the working practices of the mine. Mudstone is normally a major component with siltstone, sandstone, seatearth and minor amounts of ironstone and limestone. Coal forms a small percentage both as fragments and as slurry. Combustion of many colliery tips, whether deliberately induced or by self-ignition, has altered the physical and chemical properties of the materials. Tips which contain a high content of unburnt mudstone may be a source of raw material for brick manufacture. Colliery waste, either burnt or unburnt, can be recycled as fill in road embankments or other construction.

There are no current operations working secondary minerals in the region, most of the waste tips have now have been landscaped and sterilised by development and the material redistributed and used in land reclamation and industrial redevelopment.

## FIRECLAY

Fireclay is a non-marine sedimentary mudstone consisting essentially of the clay mineral kaolinite with varying proportions of hydrous mica and quartz, together with some minor impurities such as ironstone nodules and carbonaceous matter. In the past the uses of fireclay stemed from its refractory nature, that is its ability to withstand high temperatures without deforming or becoming chemically unstable. These properties are dependant on the alumina content which is generally between 40 and 45% for these kaolinitic clays. The value of the raw material depended greatly on the content of alkalis, iron oxides and carbon. However, fireclays are now valued chiefly as a raw material in the manufacture of high-quality, weather resistant, buff-coloured facing bricks.

Fireclay occurs commonly in association with Carboniferous coal-bearing strata or silica sandstones in the Passage Formation. These clays are therefore shown as coincident with coal and silica sand on the map.

Fireclay resources can be found in Carboniferous strata, concentrated in the Passage Formation and also the overlying Coal Measures. In Falkirk and Clackmannanshire these rocks commonly occur around the edge of the Central Coalfield syncline which runs north-south though the region. The largest resource is in the Passage Formation, which includes some of the most valuable fireclays in the UK, here bands of fireclay typically 2-3 m thick (but up to 9 m thick) occur.

Fireclays near the top of the Passage Formation are a less attractive resource being of a lower grade and are entirely absent in Clackmannanshire. The most recent workings have been located on the eastern side of the Central Coalfield where the quality is highest, but operations ceased in the early 1980s due to the decline in the demand for highly refractory fireclays.

Fireclays from the Lower Coal Measures are associated with economic coal seams unlike fireclays of the Passage Formation. They occur as seatearths to coals and are generally only extracted contemporaneously with coal. This industry has declined along with coal mining but may restart with the opening of new open cast coal sites in the region.

Relatively little fireclay has been produced from the Fife coalfield and no refractory fireclays are known to be extracted currently, although there are several active opencast coal operations. In general the fireclays in Fife appear to be poorly developed and sandy. Some fireclay mining was centred on Dunfermline, around Halbeath and Townhill. Fireclays from the Limestone Coal Formation were worked and probably the Lilliehill Fireclay was most widely extracted, lying immediately below the Index Limestone. Another fireclay that was quarried locally was that just below the Charlestown Main Limestone in the Lower Limestone Formation.

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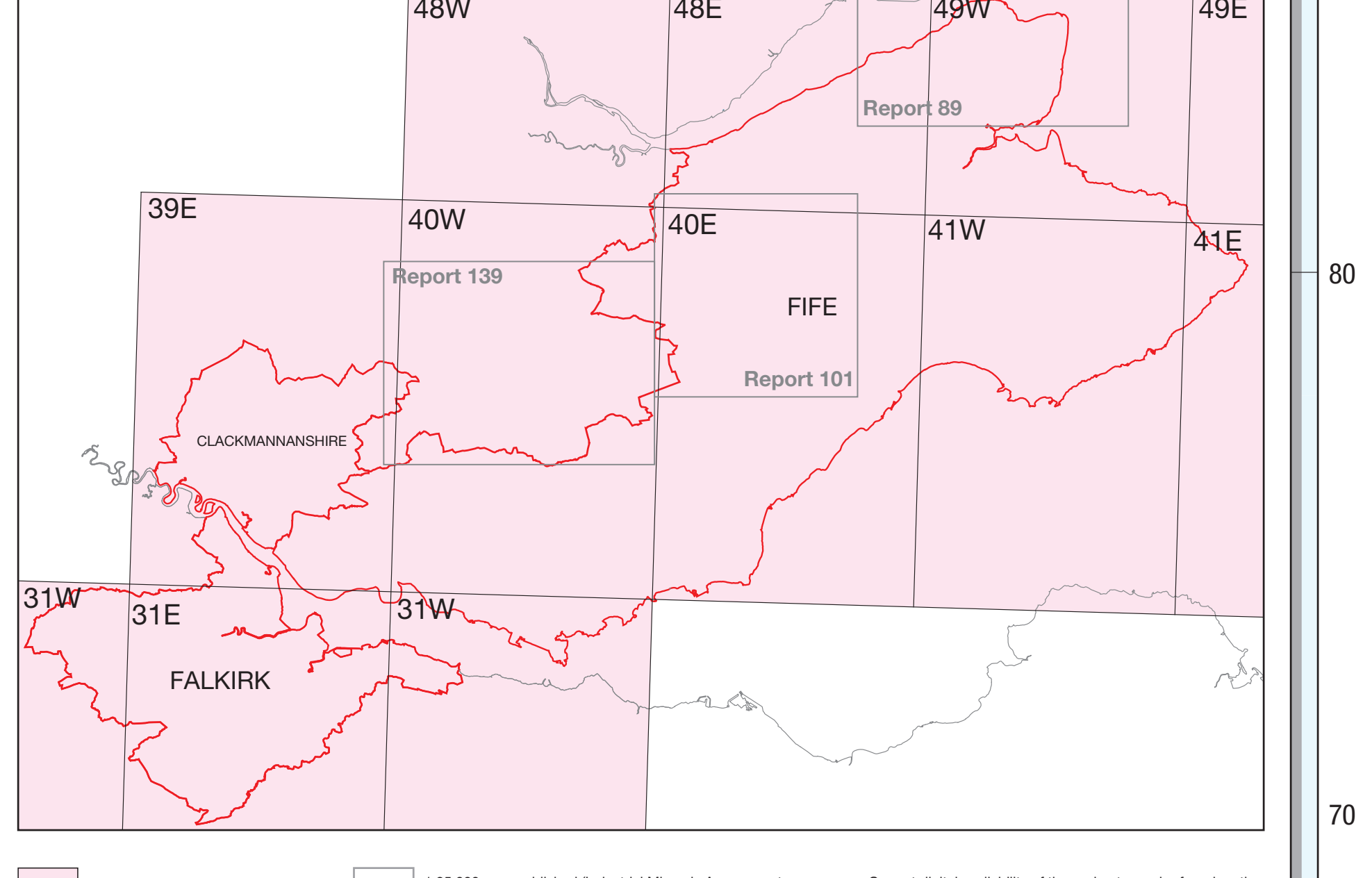
**BGS maps covering Clackmannanshire, Fife and Falkirk**



■ 1:50 000 map published

☐ 1:25 000 map published (Industrial Minerals Assessment Sand and Gravel Resource Map)

Current digital availability of these sheets can be found on the British Geological Survey website: www.bgs.ac.uk